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The potential of blockchain technology in solving green supply chain management challenges

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Abstract
Blockchain technology has gathered plenty of interest among academia and in companies for its potentially revolutionizing effect on industries and society by increasing traceability, transparency and trust among transacting parties. One of the many applications of blockchain exists in the context of supply chain management, specifically environmentally sustainable or green supply chain management, which is also a trending research topic due to the pressing state of the environment, increased awareness and regulation. Blockchain technology is still emerging and research on its potential in the area of green supply chains is sparse. This thesis combines these two trending topics by exploring the connection of the core characteristics of blockchain and the challenges in green supply chain management that the technology could potentially help in solving. It therefore contributes to the early work on the subject of blockchain's role in green supply chain management challenges and guides further research into the matter.

Keywords blockchain, supply chain, sustainability, green supply chain management

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1 INTRODUCTION

There is increasing interest in blockchain technology among academics, companies and governments for its potentially revolutionizing effect on how businesses, industries and societies operate. For example, global spending on blockchain solutions is expected to more than double from the $945 million dollars in 2017 to $2,1 billion in 2018 (International Data Group, 2018). It is not merely a disruptive technology that overthrows conventional business models with more efficient solutions, but a foundational technology that creates new structures for economic and social systems.

Hence the potential of blockchain is often compared to that of the arrival of TCP/IP (transmissions control protocol/internet protocol), on which the internet was built and today over half of the most valuable companies in the world are internet-based platforms (Iansiti & Lakhani, 2017; Swan, 2015). Considering how the internet and its applications have redefined business and virtually every aspect of our lives, blockchain poses an exciting research field. If the development of the technology follows a similar path to the TCP/IP, the most transformational applications are still decades away. But the research of the possibilities is valid in order to be prepared while the technology matures.

Essentially, blockchain is a database for records of transactions, such as a traditional ledger. What makes it unique is that it is a ledger that is open and distributed – meaning that there is no need for a a single central authority or third party to verify, control, store and forward information (Iansiti & Lakhani, 2017; Ølnes et al., 2017). Each participant has access to the entire database and information is communicated directly between peers; everyone is able to examine the ledger but no one controls it (Kosba et al., 2016; Swan, 2015). In addition, strong cryptography ensures that the data, once put on the blockchain, is irreversible and virtually tamper-proof (Sarkis, 2017; Swan, 2015). These are the reasons for the explosion of enthusiasm in the technology.

To put it practically, it enables applications that could previously operate only through a trusted third party (such as a bank, in order to guarantee secure transactions), to function in a decentralized environment with no central authority needed, while accomplishing the same degree of functionality and certainty (Christidis & Devetsikiotis, 2016; Nakamoto, 2008). This was previously impossible. The information on the blockchain is considered to be trusted, transparent and immutable (Iansiti & Lakhani, 2017; Sarkis, 2017).

Furthermore, blockchain as record for transactions does not only apply to the movement of money. The transaction can be movement of anything of value, such as a product or a piece of data, like a document, certificate, event or identity (Chapron, 2017). Anything that can be digitalized and assigned a unique digital identifier can be included in the blockchain ranging from land registers to votes and supply chain information (Chapron, 2017). In a survey report from World Economic Forum the majority of 800 executives and experts in ICT (information and communication technology) predict that 10% of the global GDP will be kept in blockchain by 2027 (World Economic Forum, 2015).

Because of the broad impact of blockchain to industries and society, the possibilities regarding research are virtually endless. However, as of now there is still not a great deal of accumulated research on blockchain. Even though most of the research and hype concerning blockchain technology seems to have been revolving around cryptocurrencies and the financial sector, there is ongoing research and development of applications outside finance, such as in power, agriculture and particularly the supply chain (Casey & Wong, 2017; Kshetri, 2018). Kshetri (2018) predicts that the supply chains are among the most likely to be transformed by blockchain. Major companies are currently looking into the technology, such as, Maersk, the world's largest container carrier and IBM are together working on commercializing blockchain solutions for the global supply chain (Buck, 2018). Utilizing blockchain technology in supply chains is one of the most exciting applications because of the sheer scale of the sector. Additionally, the supply chain industry is connected to multitudes of other industries so that innovation utilized there has the potential to trickle down broadly across the economy (Delgado & Mills, 2018).

Due to its capability to replace trusted third parties as facilitators of transactions, the blockchain technology is set to impact especially industries that depend on trust, such as supply chains that tend to be complex, global co-operations of companies with misaligned interests and a number of information, material and financial flows that require management (Casey & Wong, 2017; Saberi et al. 2018). Information technology has enabled companies to do business instantaneously on the other side of the world without ever meeting, but bureaucracy and third parties are needed to ensure security and trust between supply chain members. The long, complex supply chains make visibility and transparency into the chain difficult, particularly beyond the first-tier of suppliers, while stakeholders demand more information of the point of origin and authenticity of the products and materials they purchase (Fung, 2013; New, 2010).

The blockchain provides a reliable record of transactions that is shared among its participants. It enables the ability for all parties to keep track of every transaction in the supply chain allowing traceability, transparency and reliability of information (Foerstl et al., 2017). Each material, component and product can be tracked through its life cycle, leading to better visibility into the supply chain, which brings forth efficiencies related to supply chain management objectives such as cost, quality, speed, dependability, risk reduction, flexibility and sustainability (Chapron, 2017; Kshetri, 2018).

Environmental sustainability requires special attention in the supply chain because it is good for business but especially because of the urgency of the global environmental crisis. Earth Overshoot day is the date when we have globally used more from nature than our planet can renew in the whole year. This year it occurred already on August 1st, the earliest it has ever been (April 11th if the world's population lived like Finland), which means that the world would currently need 1,7 planets to be sustainable. (Global Footprint Network, 2018). Environmental management and sustainability has become an important issue in organizations due to governmental regulations and growing stakeholder pressure, that rise form increased awareness to preserve the natural environment (Azevedo et al. , 2011; Govindan et al. , 2015). With the popular idea of present day business that whole supply chains compete, not just individual companies (Christopher & Towill, 2001) and the fact that the lead company is often held accountable for the negative environmental performance of its suppliers (Ehrgott et al, 2013; Vanalle et al., 2017), environmental sustainability has become a supply chain imperative, not just an organizational one (Vachon & Klassen, 2006).

This is why green supply chain management (GSCM) is so important for a company's environmental management. GSCM is the integration of environmental thinking into supply chain management by using various green practices including, but not limited to eco-design, life cycle assessment, green purchasing, green logistics and transportation, reverse logistics, environmental technologies and collaboration with suppliers and customers (Govindan et al., 2015; Hervani et al., 2005; Srivastava, 2007; Zhu, Sarkis, & Lai, 2008). The interest in the topic has increased tremendously in academia and in practice. During the last decade, amount of articles published in the GSCM field has risen exponentially (Shan & Wang, 2018)

In light of the above observations of blockchain's potential in the supply chain context and the growing importance of GSCM, this thesis explores the linkage between these two topics. Research on blockchain is still scarce and scholars have barely begun to study its impact on different organizational activities. Therefore, this thesis is part of the early work of exploration of the subject. The objective is to develop a general framework of how the blockchain can help to solve challenges in green supply chain management to guide further research into the matter.

1.1 Research objectives and research questions

The research question of this thesis is *how can blockchain technology contribute to solving the challenges of green supply chain management*. The objective of the research is to answer this question with a literary review of the features of blockchain and GSCM and its challenges, and from the observations develop a tentative framework of how blockchain can contribute to the solving of challenges in GSCM.

1.2 Scope of research

This thesis will include a general level introduction to blockchain and its characteristics and will not look into very specific technical operation nor the implementation steps of the technology. Regarding supply chain management, the focus is on GSCM and the environmental dimension of sustainability. It is worth noting that the concept of sustainability has moved from purely environmental towards a triple bottom line approach (environmental, social, economic), but the interaction of these different components adds to the complexity of the issue and would not be covered in a bachelor's thesis. The research covers GSCM and its challenges in a general level and will not be limited to specific industries or geographical areas.

1.3 Structure of the research

The basis for the thesis is the literature review that consists of two parts: the first is an introduction to blockchain technology and its characteristics and how they fit the supply chain context. The second part is about GSCM and its challenges. The results chapter that follows discusses the results by combining the observations from the previous chapters to a very general framework. The thesis concludes with discussion of implications to research and practice and suggests areas for future research on the subject.

1.4 Key concepts

Blockchain technology: “The technology at the heart of bitcoin and other virtual currencies, blockchain, is an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way.” (Iansiti & Lakhani, 2017, p. 120)

Supply chain management: “Supply chain management is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and stakeholders.” (Lambert, Cooper, & Pagh, 1998, p. 1)

Sustainable development: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987, p. 43)

Sustainable supply chain management: “The creation of coordinated supply chains through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information, and capital flows associated with the procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the short- and long-term.” (Ahi & Searcy, 2013, p. 339)

Green supply chain management: “Integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life.” (Srivastava, 2007, p. 54)

2 RESEARCH METHODOLOGY

The goal of the literature review is to get an understanding of the main features of blockchain technology and GSCM. Subsequently, the literature review will consist of two parts. The observations from these will result in a general framework of how the blockchain technology can benefit GSCM. Next research methodology is presented for the research as a whole and for the blockchain and GSCM parts, respectively.

2.1 General methodology

The research of this thesis is conceptual. The goal is to find potential ways that blockchain technology can impact the challenges of GSCM. The research is conducted with an inductive approach. The inductive or "bottom-up" approach is the use of single observations to build generalizations of the phenomenon that is being studied (Lodico et al. 2010). This is done by studying the features of blockchain technology and GSCM and making observations from the literature that currently exists. From these observations, patterns are made to develop a tentative framework for using blockchain for the challenges GSCM. The tentative framework introduces therefore a hypothesis for further research on the subject. Because this thesis represents the early work on blockchain's impact on GSCM, it is by necessity exploratory. Also, the funnel method is utilized, meaning that the research is conducted by starting from a broad and general perspective before moving on to more specific issues in the subject.

2.2 Data acquisition

For the data acquisition, Scopus was the main source of material. It was chosen because of the large scope of management and engineering material (Ahi & Searcy, 2013). The search was conducted using different combinations of keywords. In a literature review it is crucial to set boundaries to the research in order to limit the material (Seuring & Gold, 2012). Next some of the criteria for material is defined.

When looking for commonly cited source material for blockchain, it became evident that many of the most cited sources where conference papers, so it was valid to include them to the search with along with journal articles. For example, with the search term "blockchain" of the top 20 most cited sources 14 were conference papers. Typically, the industry interest in technology related conference papers is high due to the shorter publishing cycles, which makes the information available faster than in academic journals. The year span of the documents found in this initial search is 2013-2018, during which the number of documents per year has risen considerably from 2 (2013) to 503 (2017)

Finding appropriate articles proved to be quite difficult. Due to the novelty of blockchain technology, particularly in use cases outside finance, it has not yet established a great deal of academic peer reviewed research. For the same reason the literature that has been published lacks accumulated citation. Because of this, references that were cited in the papers were used to find additional relevant material. To assess the quality and credibility of the different sources, Julkaisufoorumi was utilized.

Another observation from the data acquisition is that in many studies the focus of the research is on Bitcoin and not in blockchain technology. This was supported in systematic review on current research of blockchain technology where Yli-huumo et al. (2016) found that in 80% of the research the focus was on Bitcoin. In addition, they stated that most of the research is focused on privacy and security perspective of blockchain. On the other hand, the research was published in 2016, and amount and variety of research increased since then. The documents that were purely about bitcoin or cryptocurrencies were excluded, but the ones that discussed the underlying blockchain technology adequately were included.

Regarding GSCM, it has accumulated established peer-reviewed research, especially during the last 10 years and therefore only journal articles and reviews were chosen in the initial search. Additionally, references from the searched material were used. The subject area is most commonly published in journals related to sustainability/ environmental management and operations/ supply chain management. As mentioned before, the focus in this thesis is on the GSCM, but some of the documents about sustainable supply chain management with the three pillar (environmental, social, economic) perspective were included, because they deal with the environmental aspect of sustainability. Also, one could argue that the economic dimension is included in the material chosen as the articles are management related. Besides, there is not a specific consensus on the definitions of green and sustainable supply chain management (Ahi & Searcy, 2013). Because of the abundance of material, highly sited material was favoured along with newer material to get an understanding of the recent developments in the field.

3 BLOCKCHAIN TECHNOLOGY

This first part of the literature review is about blockchain technology and its role in the context of supply chain management. This chapter introduces the blockchain in a general level, discussing its background, what is it, how it works, the concept of smart contracts, briefly summarizing the key characteristics and finally the kind of benefits it can bring into the supply chain context.

3.1 Background and the double spending problem

Blockchain technology was created in 2008 as the underlying technology behind the first cryptocurrency, Bitcoin, by a person whose identity has not been confirmed but going by the pseudonym Satoshi Nakamoto. In the pioneering paper "Bitcoin: A Peer-to-Peer Electronic Cash System" blockchain was introduced as the public ledger for the transcations of the Bitcoin system, although the ledger was described using the words "block" and "chain" and the term blockchain became popular later (Nakamoto, 2008). The focus was clearly on the bitcoin as an application and blockchain was merely a concept behind it that made the system feasible to begin with. The enormous potential of the blockchain for a wide set of applications outside cryptocurrencies was not obvious at the start.

The purpose of the system was to solve a problem that is at the root of any electronic transaction: the double spending problem (Nakamoto, 2008). With physical transactions there is no such problem, as the payer cannot use the money twice or give an item to several people; they have physically handed it over. But in electronic transactions a trusted third party, such as a bank or credit card company, is required as a middleman to process and verify the transaction because otherwise the payer could technically spend the money more than once. Similarly, when sending a physical letter only the receiver has a hold of it, but when sending an email, both the sender and receiver have a copy of the email file. Without the bank the parties in a transaction directly with each other have no way of knowing if the money has already been spent or not, so the role of the bank is to bring trust to the equation. For this reason it is typical for the transaction system to be entirely centralized, where the third party manages and has a hold of the data (Yli-Huumo et al., 2016). This is how the double spending problem has been solved as of now. However, the downside is that the involvement of third parties causes additional transaction costs and makes the system depend heavily on them (Iansiti & Lakhani, 2017; Kosba et al., 2016).

This is where the blockchain technology steps in. It can render this trust based model unnecessary and enables a world where parties are able to transact directly without trusted middlemen (Gupta, 2017b). The objective of the technology is to offer a decentralized environment, where the problem of double spending is solved with a distributed database in peer-to-peer network that relies on strong cryptographic proof rather than trust so that no third party or central authority is needed to verify transactions (Nakamoto, 2008). Next, this is explained in more detail.

3.2 What it its

Essentially, blockchain is a ledger, that much like traditional ledgers or databases, stores and maintains information of practically anything of value (such as objects and people) and the interactions (transactions) between them (Iansiti & Lakhani, 2017; Swan, 2015). Anything that can be digitalized and assigned a unique digital identifier can be included in the blockchain such as money, products, or a piece of data like a document, event, certificate or identity of a person (Casey & Wong, 2017; Chapron, 2017). However, the blockchain functions as a ledger that differs in two crucial ways. First, unlike the typical centralized systems, blockchain is a distributed ledger, meaning the data is stored and maintained by network of participants rather than a central authority as previously explained. This is illustrated in Figure 1. Each of the participants of the network or "nodes" take part in maintaining the system and communication happens peer-to-peer. (Christidis & Devetsikiotis, 2016; Swan, 2015; UNDP, 2018)

Second, the data is gathered and ordered securely using complex cryptography. The result is a continuously growing list of chronologically ordered records or "blocks" that are linked together in a "chain"; hence the name (Gupta, 2017a). Therefore, once data is added to the blockchain, it cannot be modified or removed (Yli-Huumo et al., 2016). However, in theory a blockchain could be taken over and modified with a so-called 51% attack where an entity possesses over half of the network power in the system, but this is extremely difficult and unlikely due to the sheer size of the network (Swan, 2015).

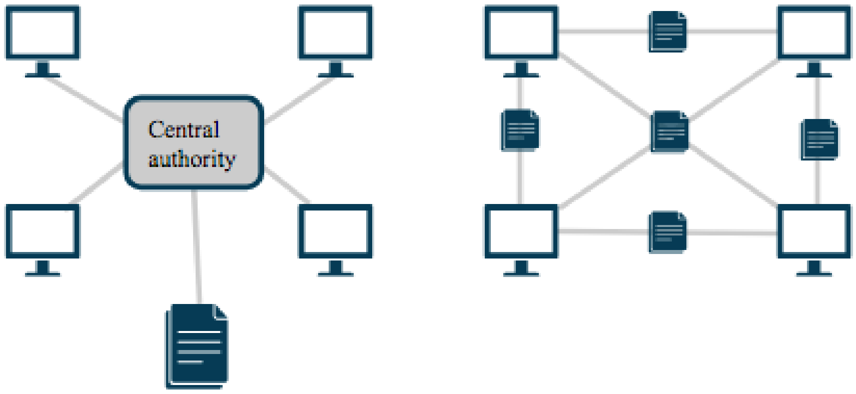

Figure 1. A centralized ledger (central authority controls and forwards data) vs a distributed ledger (each participant holds a copy and communicates peer-to-peer).

Blockchains can classified into two groups: public or private. The difference in that in public blockchains such as the Bitcoin, anyone can join the platform, whereas in private blockchains the participants consist of a closed group of members (Underwood, 2016). Christidis and Devetsikiotis (2016) argue that private blockchains are preferable when the participants want to predetermine the members and thus operate in a more regulated setting by controlling who has access to the information. This would most likely be the case in a blockchain used by an industry or a supply chain.

3.3 How it works

The blockchain is gradually built of chronologically ordered blocks of data that are chained together as the transactions occur. Each of these blocks is identified by a unique string of characters, a complex cryptographic code called a “hash”, which includes the hash of the previous blocks as well (Christidis & Devetsikiotis, 2016; Tian, 2016). An example of this is presented below in Figure 2. This means that each block has the data of all the transactions preceding it and the links between blocks are virtually unbreakable. The functionality guarantees that if there is any attempt to change or delete a previously created block in the chain, the hash would not match the blocks before it anymore and the network is alerted. And because everyone has a copy of the entire blockchain, the whole network would be notified by the tampering. (Christidis & Devetsikiotis, 2016; Iansiti & Lakhani, 2017).

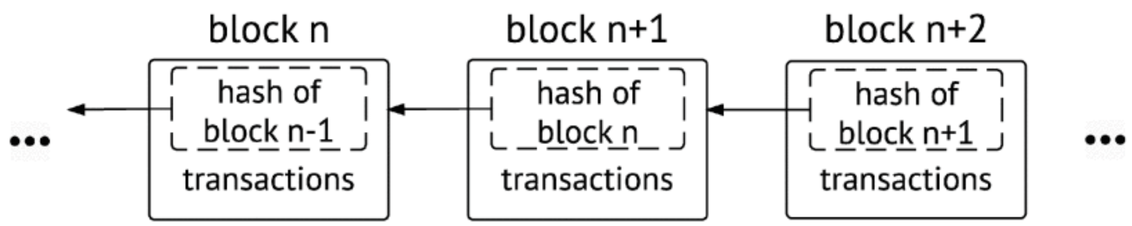

Figure 2. Portrayal of the blocks chained together with each block carrying a list of transactions and the hash of the previous block.
(Christidis & Devetsikiotis, 2016)

To put it simply, the adding of a transaction on the blockchain works as follows (Christidis & Devetsikiotis, 2016; Swan, 2015; UNDP, 2018):

1. The participants interact in the blockchain by using private/public key cryptography to sign the transactions before sharing it with the network. Essentially this verifies their identities, while allowing members to stay anonymous if they want.
2. When a transaction occurs, it is recorded and shared among the other nodes in the network to be validated. The network validates the transaction using an agreed upon consensus mechanism involving complex algorithms. If no consensus is reached, the block is rejected.
3. After the transaction is verified, it is combined with previous transactions to form a new block as described.
4. Finally, the new block is added to the ledger, becoming a permanent and immutable part of it.

3.4 Key characteristics

To briefly summarise what has been discussed above, there are some key characteristics of the blockchain, that regardless of specific configuration, provide us with certain benefits. Additionally, they enable another characteristic of the technology, which is the use of smart contracts. These are described below:

Distributed peer-to-peer system: All the participants in the system have a copy of the ledger and have access to all of the data without a third party. When a change, such as a new transaction occurs in one copy, all the other copies are updated automatically (Iansiti & Lakhani, 2017). Because each participant has complete visibility to the ledger and its history, the system is transparent. Furthermore, the system is resilient and tolerant of node failures since the information remains available in the case of part of the network going offline the system (Christidis & Devetsikiotis, 2016).

Immutability of the data: As explained above, once a transaction is added to the ledger it is linked to a chronological chain of all the previously added blocks of transactions and cannot be changed. Strong cryptography is used in the form of complex computational algorithms to ensure that the records are permanent and unchangeable (Casey & Wong, 2017). This allows members of the system to trust that the data is secure, promoting information sharing among the participants.

Self-execution of smart contracts: One of the interesting features of blockchain technology is its ability to create smart contracts. In the blockchain context smart contracts are essentially digital agreements, that automatically process and enforce a contract between two parties according to predetermined rules (Swan, 2015). Swan characterizes them as being autonomous, self-sufficient and decentralized. The smart contracts thus assure the performance of a contract and remove the need for third-party resolution (Christidis & Devetsikiotis, 2016). For example, an invoice is automatically paid once particular, agreed upon conditions are met, such as when a shipment arrives. Furthermore, through smart contracts laws and regulations could be set up in the blockchain so that they would be automatically enforced as well (Nakasumi, 2017). Because of these aspects, the performance of contractual partners is virtually ensured and there is less need for conventional ways to establish trust between them. Neither party needs to hope that the other fill their end of the deal.

3.5 Blockchain in supply chain management

The blockchain and the characteristics it offers has the potential to improve the supply chain through a number of ways. Casey and Wong (2017) describe the technology as a global system for mediating trust and transparency. Saberi et al. (2018) argue that it has the potential to increase transparency, reliability and availability of information for all of the supply chain stakeholders. Global supply chains are complex, opaque structures, with often misaligned interests among the variety of members (Casey & Wong, 2017). Information is in organizational silos, demanding burdensome and error prone reconciliation with each member's internal records. Blockchain provides transparency, verifiability and auditability of the information and the actions of members of the supply chain (Casey & Wong, 2017; Iansiti & Lakhani, 2017; Steiner & Baker, 2015). Kshetri

(2018) predicts that blockchain can help companies meet key supply chain management objectives, including cost, quality, speed, dependability, risk reduction, sustainability and flexibility. The technology enables concrete improvements in the supply chain including better visibility through tracking the location and state of goods, but also in more abstract, although equally important ways, such as in increased trust to do business with supply chain partners leading to better integration (Steiner & Baker, 2015).

3.5.1 Recording, tracking and verifying trades

Blockchain technology is believed to be especially powerful with the combination on internet of things (IoT) (Kshetri, 2018). IoT means a network of connected physical devices; basically, any object that is equipped with electronics and software so that it is able to collect and exchange data. Products and materials can be linked to the electronic information and recorded to the blockchain as the flow through the supply chain (Sarkis, 2017). These devices produce a lot of data that needs to be stored securely and reliably. As long as the information that entered is accurate to begin with, for example from a sensor, the blockchain is able to ensure its immutability once it is added to the ledger (Catalini, 2017; Christidis & Devetsikiotis, 2016). Kshetri (2018) states that the combination of blockchain with of Internet of things (IoT), RFID tags, barcodes, sensors and GPS tags and chips allow the secure tracking of products, shipping containers and vehicles through each step of the supply chain from the point of origin to the end-consumer.

In addition to the quantity, location and state (e.g. temperature) of the assets, the supply chain information can also be securely tracked, such as bill-of-material, shipment data and invoices (Kshetri, 2018; Sarkis, 2017). The technology offers a way to verify certifications of products, including those of quality or sustainability (Sarkis, 2017). This can be done by for assigning digital identification, a form of a product "passport" that proves authenticity and origin of the product with an auditable record of its journey (Kshetri, 2018; Steiner & Baker, 2015).

3.5.2 Traceability

Because of the capabilities above, blockchain technology can enhance the traceability in supply chains, which refers to the ability to of tracking information such as the provenance, history, applications and location of products and materials in the supply chain (Kelepouris et al., 2007; Tian, 2016). Tian (2016) studied the use of blockchain as a part of a of agri-food supply chain traceability system and concluded that the system could allow information identification, inquiry, tracking, monitoring and tracing in the entire supply chain. Blockchain can facilitate an uninterrupted chain of custody by tracking products through each step of the products journey (Steiner & Baker, 2015), which provides a record of ownership for each product (Abeyratne & Monfared, 2016). Therefore, blockchain could be part of the solution to the problem of complexity lack of visibility of supply chains especially beyond the first tier of suppliers.

3.5.3 Transparency

A major benefit associated with the characteristics of blockchain is its ability to provide transparency to supply chains (Steiner & Baker, 2015; Tian, 2016). Data can be fragmented and in information silos in different organizations in the supply chain which contributes to information asymmetry between members. Traceability is therefore not enough to ensure transparency, when the information is controlled and needs to be accessed through a third party, making it vulnerable to fraud (Tian, 2016). With blockchain each member in the supply chain has access to an identical copy of the data in real time, which would provide a single source of truth to the system and enable immediate inspection and auditing of the information (Abeyratne & Monfared, 2016). Consequently, the members of a supply chain would have a greater and timelier visibility of the products and activities in the supply chain (Casey & Wong, 2017). The decentralized nature and immutability of information are the core characteristics that would allow the transparency of blockchain in supply chains. The ability of blockchain to provide reliable, real-time information in the supply chain context also relates to the principle of information substitution, which means that when you have accurate information about materials and products, it replaces the need to hold durable materials and products. Consequently, information substitution can significantly decrease transportation, energy usage and inventory in supply chains. (Sarkis, 2012)

3.5.4 Smart contracts

Smart contracts on blockchain can enable the automation of multi-step processes and interactions between transaction parties (Christidis & Devetsikiotis, 2016). To put it simply, when the parties in the supply chain have agreed upon a set of rules and outcomes, the smart contract can automatically execute and enforce them (Swan, 2015). For example, the arrival of shipment could execute a payment or reaching certain measured conditions such as speed or quality would automate transferal of incentives. If the conditions of the contract are not met like exceeding emission caps, repercussions such as fines or return of payment could be executed without human enforcement. Therefore contracts and even regulations could be automated in supply chains (Nakasumi, 2017). As mentioned, smart contracts could also allow the automation of agreed upon incentives. In conclusion, smart contracts ensure that supply chain parties involved comply with the predetermined terms of an agreement. Furthermore, by reducing human involvement in the creation, execution and enforcement of the contract, related costs are decreased (Abeyratne & Monfared, 2016).

3.5.5 Trust among supply chain members and customers

The blockchain allows parties that do not trust each other to interact in a predictable way (Christidis & Devetsikiotis, 2016). Cheng (2008) states that information sharing is a precondition for trust in supply chain relationships and blockchain provides a single source of information that all the members know to be accurate, reliable and secure. Every stakeholder in the supply chain can track products and shipments along the supply chain (Tian, 2016). As discussed above, the use of smart contracts would further increase the trust in supply chains by being able to trust that terms of contracts are executed and enforced automatically. A third party would not be needed to facilitate trust between supply chain members because of decentralized, immutable nature of the system (Gupta, 2017b). It automatically resolves the issues of disclosure and accountability between individuals and organizations with misaligned interests since the data in the blockchain and the terms of a smart contract can be trusted to be accurate and secure from tampering (Christidis & Devetsikiotis, 2016). Another perspective to this issue is that blockchain can actually remove the need for trust since it’s replaced with confidence in the system which does not give control to a single participant.

The increased trust can extend to consumers as well. Transparency of information of the products could greatly increase consumer’s trust in the products and the company, since they would be able to access information of the activities in the supply chain, like a product’s origin, journey and authenticity, and make more informed consumption decisions based on it (Steiner & Baker, 2015; Tian, 2016)

3.6 Challenges

Bunger (2017) suggests that one of the problems concerning blockchain is the hype around it, which makes stakeholders want to dive head first into it by applying it everywhere and anywhere, rather than starting from identifying and defining a problem that needs solving. The technology has been described to be at the height of inflated expectations on Gartner's hype cycle, which is why cautiousness is advised (Saberi et al, 2018). The reasons for the suggested caution are challenges of blockchain technology including, but not limited to: technological, organizational, cultural and behavioural challenges such as cost of deployment, scalability, immaturity, lack of standards, top management support, organizational policies, governmental support and the expertise of employees (Abeyratne & Monfared, 2016; Khaqqi, et al., 2018; Swan, 2015). Specifically, global supply chains are complicated structures that require the parties to follow various established laws, regulations and institutions related to ownership and possession in multiple jurisdictions (Kshetri, 2018).

When assessing how blockchain technology can be applied to make supply chains more environmentally sustainable it is valid to assess how sustainable the technology itself is. The mining process of validating the blocks of transactions is computing-intensive requiring vast data centres, and therefore energy-intensive. However, it is necessary for the security of the technology and solving the double spending problem. Vranken (2017) studied the sustainability of bitcoin, a public blockchain, and he argues that energy consumption is not a primary concern because of the competitiveness of mining; only those with the most efficient mining and least energy-demanding hardware that lead to lower energy costs will prevail. Vranken adds that less decentralized private and consortium blockchains would require much less energy but with expense of reduced security. But if the users in the private blockchain were a group of vetted members it would not be such a concern. Another new alternative in development for the energy-intensive mining process is the use of complex financial instruments that would provide the system with the same or even higher level of security (Gupta, 2017a).

Ultimately to be able to conclude the environmental sustainability of the blockchain in supply chain applications, the energy use of the technology would need to be compared to the increase of sustainability that it delivers. The difficulty is that sustainability in supply chains is harder to measure comprehensively as opposed to more quantifiable measures such as cost and speed (Linton et al. 2007). Then again blockchain technology itself has the potential to make sustainability in supply chains more quantifiable (Kshetri, 2018).

4 GREEN SUPPLY CHAIN MANAGEMENT

This second part of the literature review begins with a brief background to sustainable development and environmental sustainability leading to the introduction of the framework of GSCM and GSCM practices. To conclude the chapter, current challenges or barriers are presented.

4.1 Green supply chain management

4.1.1 From sustainable development to green supply chain management

There is increasing acknowledgment in organizations that they must deal with the issues of environmental sustainability in their operations ((Rajeev et al, 2017). The most widely used definition for sustainability is the concept of sustainable development from the Brundtland report (WCED, 1987): *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* This is rather vague for practice and thus a widely used, more operational perspective to sustainability is that of the triple bottom line by Elkington (1998), which integrates environmental, social and economic dimensions of sustainability in order to evaluate the performance of organizations more broadly.

The environmental aspect of sustainability is particularly pressing and especially in the supply chain context. Development of industry, economic growth has led to a large increase in consumption habits, while globalization has given rise to vast streams of goods round the world (UNDP, 2018). Consequently, the production, transportation and use of these goods have contributed to environmental problems such as global warming that occurs from to the extensive amount of emissions from industry (Dekker et al., 2012; Rajeev et al., 2017). This has led to increasing pressure form stakeholders such as customers, suppliers, governments and NGO's, forcing organizations to assess the environmental consequences of their production activities (de Oliveira et al., 2018). These are the ultimate reasons behind the development environmental initiatives and practices in organizations, such as GSCM. Furthermore, environmentally considerate business has been found to impact the bottom line positively in the form of reducing inefficiencies and improved brand image (Zhu et al., 2013).

4.1.2 Definition

Environmental sustainability in the supply chain context has been discussed using a variety of terms, of which the ones that combine the topics most closely are the cross-disciplinary fields of sustainable supply chain management and GSCM. Many literature reviews have been conducted on these two subjects during the last ten years and one of the issues that comes up is the abundance of overlapping definitions for the two terms (Shan & Wang, 2018). Ahi and Searcy (2013) concluded that sustainable supply chain management is basically an extension of GSCM, although the overlapping was confirmed. This amount of definitions makes sense, since both the concepts of supply chain management and sustainability are complex issues that have range of definitions depending of the focus of a given researcher.

The definition of GSCM has ranged from mere green purchasing to the full integration of supply chain flows from supplier to end customer and reverse logistics (Zhu & Sarkis, 2004). Hervani et al. (2005) viewed GSCM as integration of specifically green purchasing, green manufacturing, materials management, green distribution, green marketing and reverse logistics. The most widely used definition for GSCM is that of Srivastava (2007): "*Integrating environmental thinking into supply-chain management, including product design, material sourcing and selection manufacturing processes, delivery of the final product to the consumers as well as the end-of-life management of the product after its useful life.*" Therefore, the main differences to supply chain management are the greater focus on the environmental aspects but also the extension of the scope. The traditional supply chain management focuses on the linear chain in the sense that it deals with the forward flow of products from purchasing of raw materials to delivery of the finished product. GSCM extends the scope by managing the forward as well as reverse flow of products and creating a closed-loop supply chain, in which end-of-life processes such as recollecting, repairing, remanufacturing, recycling and proper disposal are utilized (Sarkis, 2017; Srivastava, 2007).

Srivastava (2007) argues that GSCM can reduce the negative environmental impacts (air, water and land pollution) and waste of resources (for example energy and materials) of industry, while improving financial efficiency (Govindan et al., 2015). Additionally, the responses of companies are evolving from a mere reactive approach to a more proactive one by merging environmentally sustainable practises into the core of their organizational strategies and policies (Srivastava, 2007).

4.2 Green supply chain management practices

GSCM practices are the practical ways of an organization to realize an environmentally concentrated strategy (Green et al., 2012b) A wide definition suggests that any actions in the supply chain, either in a company or together with external stakeholders, in order to reduce environmental impacts in any way are counted as GSCM practices (Azevedo et al., 2011). In addition, the practices of GSCM vary between reactive practices such as monitoring of environmental management programs to adoption of proactive practices such as reverse logistics and incorporating environmental innovations (Zhu & Sarkis, 2004). In fact, a common definition of the scope of practices does not exist, depending again heavily on the focus of a given researcher. GSCM practices can be broadly divided into internal practices and external practices (Rao & Holt, 2005; Zhu et al., 2013) Internal GSCM practices refer to the practices within the focal company, whereas external practices require cooperation between external stakeholders like suppliers and customers (Zhu et al., 2005) On the other hand, external GSCM practices should be based on and coordinated with an organization's internal practices. Environmental, operational and economic performance improvements may result from both internal and external GSCM practices (Seuring & Müller, 2008b; Zhu et al., 2013).

The most cited literature on GSCM practices by Zhu and Sarkis (2004) points to the classification of four core practices: internal environmental management, external GSCM practices, investment recovery and eco-design. Zhu et al. (2008) developed the classification by adding green purchasing to the list. In addition, they argue that these factors are a starting point and issues such as reverse logistics and external cooperation should be considered in future research. Vachon and Klassen (2006) categorize external interorganizational GSCM practices into two groups: environmental collaboration and environmental monitoring, meaning that the option is to either use mutual problem solving or inspection and risk minimization to improve environmental management. Figure 2. demonstrates a common example of the graphical presentation of GSCM by Hervani et al. (2005), where the practices are linked while each phase consumes energy and produces waste. The model also demonstrates how reverse logistics functions close the loop of the traditional forward flowing supply chain.

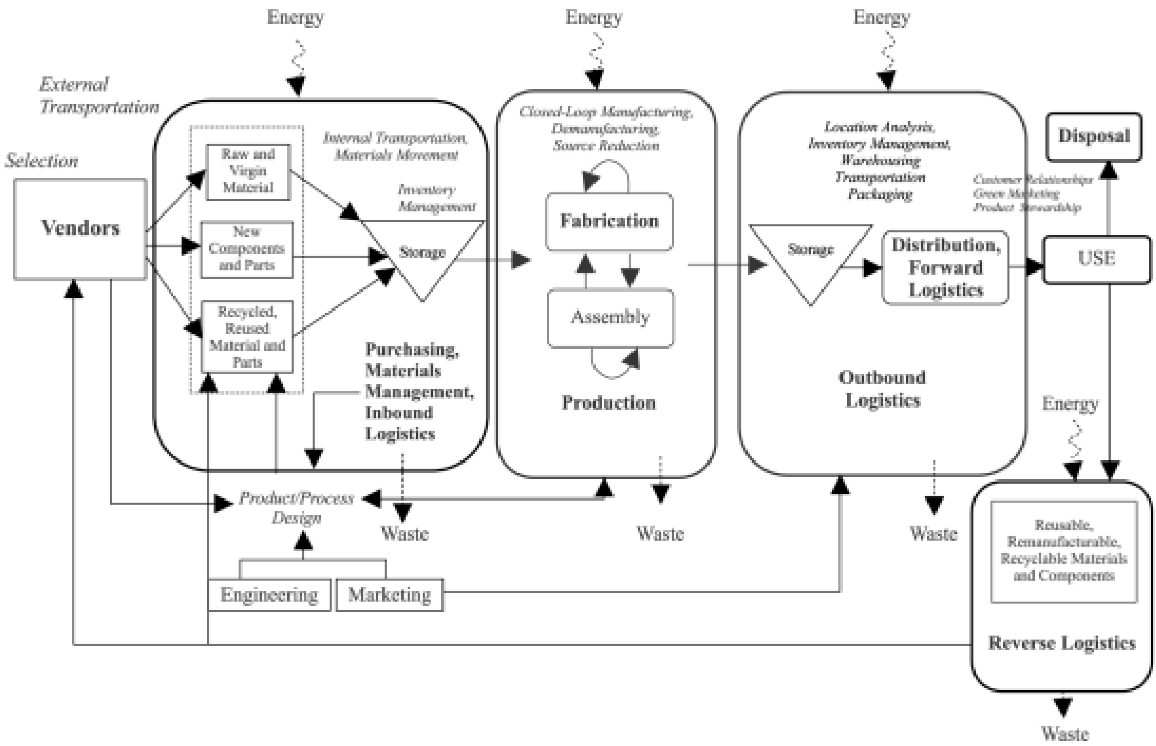

Figure 3: A model for GSCM and GSCM practices (Hervani et al., 2005)

4.3 Challenges of green supply chain management

Even when the importance of GSCM is comprehended, there are still a variety of barriers or challenges companies face when considering implementing GSCM. There are several challenges that are associated with supply chain management in general, but some of them are especially relevant in the context of GSCM. Supply chains today are complex structures involving even hundreds of stages across a long chain of scattered geographical locations, with misaligned interests and each party having their information in organizational silos. This makes it extremely hard to track products and information associated with them, especially beyond the first tier of suppliers (New, 2010; Rauer & Kaufmann, 2015; Seuring & Gold, 2012). Furthermore, there is a lack of trust in the information and in other supply chain partners. At the same time integration of supply chains and collaboration is seen as a source of competitive advantage in today's supply chain management (Vachon & Klassen, 2006).

Walker (2008) divides the barriers to internal barriers, such cost concerns, and external barriers, such as poor supplier commitment, stating that there are generally more external than internal ones. The barriers have also been found to differ based on the size of the focal company and type of industry (Govindan et al., 2014). It boils down to the fact that in order to influence the environmental impact of a company's production cycle activities, integration of the GSCM practices in the entire supply chain is required. In the current multi-tier supply chain networks, the success of GSCM practices is not only a result of buying company's own efforts but it relies heavily on the actions and contributions of suppliers upstream (Rauer & Kaufmann, 2015). Because of the importance of a life-cycle perspective and supply chain integration to achieve environmental performance improvements, the focus of these barrier lies in the external ones. Next some of the challenges and barrier of GSCM are reviewed. Many of the barriers identified are interrelated, for example the lack of transparency and trackability contribute to lack of trust and vice versa.

4.3.1 Cost concerns

Traditionally cost as a part of economic performance has been a priority measure in supply chains. While the adoption of GSCM practices may increase the economic performance in the long-term, the required initial investment is still significant (Agyemang et al., 2016; Walker et al., 2008). Therefore, cost concerns are among the biggest barriers for implementing GSCM practices. These costs include direct costs and transaction costs (Luthra et al., 2011). Furthermore, there is the issue of being able to transfer these costs related to GSCM to prices of the products i.e. if customers are willing to pay a premium for sustainability.

4.3.2 Issues of assessing environmental performance

GSCM means that environmental issues are measurable issues and therefore traceable issues (Sarkis, 2017), but research shows that sustainability is less quantifiable and thus harder to measure in supply chains compared to measures such as cost and speed (Linton et al., 2007). Foesrtl et al. (2018) states that the inability to observe the sustainable behaviour or performance in their supply chains is one of the most crucial challenges in sustainable supply chain management. Environmental sustainability is something that cannot be determined by the final product alone and needs information from all the processes involved in the value chain. For example, the materials used in a product give some insight of the impact, but issues related to transportation or energy efficiency cannot be deduced based on the final output. Performance measurement is crucial for company to be able to plan, design, implement and monitor the effectiveness and efficiency of their systems (Hervani et al., 2005). GSCM requires the capabilities to measure environmental indicators and get quality environmental data to assist decision making and asses the performance of GSCM practices (Rao & Holt, 2005; Rauer & Kaufmann, 2015). This environmental information can be hard to measure and get from the various members of the supply chain (Agyemang et al., 2018). This is a therefore a substantial barrier that is closely related to challenges related to trackability and traceability.

4.3.3 Lack of integrated information and traceability systems

Agyemang (2018) found that a the lack of integrated information and traceability systems is a key barrier in supply chains and that implementing it will improve the level of trust and contribute to making suppliers more committed, while reducing the uncertainty of benefits among supply chain members. It is necessary to track all of the material and energy flows of a product from retrieving the raw material to disposal at the end of life (Srivastava, 2007). Ability to track products is crucial part of traceability but sustainability related tracking systems are still commonly based in papers and reports, which makes them susceptible to errors and fraud (Kshetri, 2018). Solutions to these challenges can also contribute to the problems of assessing environmental performance by providing inputs for measurement: an effective information and traceability system can facilitate information flow and exchange in supply chains (Luthra et al., 2011). This kind of integration and cooperation has been linked to more effective management of environmental issues in supply chains (Vachon & Klassen, 2006)

4.3.4 Lack of transparency

In a 10 tier supply chain, the systematic tracking of issues related to environmental sustainability is hard to accomplish due to lack of transparency in the chain. Rauer and Kaufmann (2015) identified lack of supply chain transparency combined with lack of influence on sub suppliers to be a structural level barrier to GSCM. This fits prior studies that highlight the fragmentation and complexity of the supply chain as notable barriers for GSCM (Walker et al., 2008). Even when imposing environmental sustainability standards to upstream suppliers, buying firms have a hard time monitoring them because of the trouble of validating the reliability of the information they do receive from suppliers. If the sustainability information is reliable, it is challenging to asses if it applies to all of the product supplied or only 10%. (Rauer & Kaufmann, 2015) The lack of transparency and difficulties associated with increase the further a supplier is in the chain.

4.3.5 Lack of customer demand and knowledge

One of the issues companies face in their decision to adopt GSCM practices is lack of customer demand for green products and services or the willingness for a consumer to pay a price premium for them (Seuring & Müller, 2008a). On the other hand other research states that increasing consumer awareness of environmental issues is one of the biggest drivers for GSCM (New, 2010; Rao & Holt, 2005), which implies that lack of general awareness of the environmental problems is not to blame. Young (2010) suggests that factors effecting the lack of demand are relatively higher prices of sustainable products, amount of time it takes to research them and insufficient information. This lack of knowledge by consumers about the environmental sustainability of products can therefore act as a barrier to adoption of GSCM (Agyemang et al., 2018; Min & Galle, 2001)

4.3.6 Lack of trust

Trust has numerous definitions and perspectives to it, but in the context of supply chain relationships trust can be described by one party's belief to have confidence in the reliability and integrity of its supply chain member and the positive outcomes that follow from it (Cheng et al., 2008). Lack of trust between supply chain members has been found to impede the adoption of GSCM (Hoejmose et al., 2012). Agi and Nishant (2017) found that the nature of the relationship between supply chain partners has a strong influence on the implementation of GSCM practices. Dependence, trust and durability the relationship were found to be especially important factors. Trust has been found to be a central factor in influencing knowledge sharing between organizations (Cheng et al., 2008). Another perspective to trust is that it has been found to reduce transaction costs in supply chains (Hoejmose et al., 2012). As such trust is an important prerequisite for effective collaboration in supply chains.

On the other hand, the increase in companies misleading stakeholders of their environmental performance or the sustainability of their products, otherwise known as greenwashing, can lead to an expansive impact on the trust and confidence of consumers and investors in sustainable products (Delmas & Burbano, 2011). As previously explained, the complexity of global supply chains makes it hard for companies to have visibility into the entire supply chain, which could be argued that enables greenwashing in the sense that the lack of visibility is an excuse for not backing up claims of sustainability adequately.

5 RESULTS

In this section the findings from the two literature views are combined. The characteristics and benefits of blockchain technology are combined with the corresponding challenges in green supply chain management and the resulting general framework is presented in Table 1. As in the previous section, the effects of blockchain to different GSCM challenges are interrelated, meaning that the concepts of measuring performance, traceability, transparency and trust do not have clear boundaries. Also, the list is not an extensive representation of the effects of blockchain in green supply chain management challenges because of the complexity of concept of supply chain management as well as of blockchain technology.

5.1 Effect on costs

The impact of blockchain technology as a part of the solution to cost concerns, especially total costs, is not very straightforward since as with the case of implementing GSCM, it requires high initial investments to implement new supply chain wide information systems (Walker et al., 2008). This is a barrier that exists even if long term positive impacts on economic performance are expected. Therefore, blockchain could contribute to the barrier of costs in GSCM. On the other hand, blockchain eliminates the need for third parties to facilitate transactions, which can reduce the related transaction costs significantly (Iansiti & Lakhani, 2017). Another way that blockchain could impact transaction costs is by increasing trust between supply chain members by providing reliable information and by using smart contracts to create, execute and enforce contractual agreements (Abeyratne & Monfared, 2016).

5.2 Effect on measuring environmental performance

Previous research has described sustainability related issues to be harder to measure (Linton et al., 2007) but blockchain could improve the measurement of environmental performance by making sustainability related indicators more quantifiable as well as meaningful (Kshetri, 2018). The combination of blockchain and IoT could provide an abundance of data from the entire value chain of products and materials from point of origin to point of consumption and beyond to end-of-life stages, which is crucial in the effective management of environmental sustainability (Srivastava, 2007; Tian, 2016). The reliability and immutability of the information on the blockchain would make sure of the quality of the information, which is required in GSCM to be able to use in decision making and in evaluating the performance of GSCM practices (Rauer & Kaufmann, 2015).

5.3 Effect on integrated traceability and information systems

The characteristics of blockchain could provide a solution to the challenges regarding traceability in GSCM. Kshetri (2018) states that the combination of blockchain with of Iot, RFID tags, barcodes, sensors and GPS tags and chips allow the secure tracking of products, shipping containers and vehicles through each step of the supply chain from the point of origin to the end-consumer. Additionally, supply chain information could be securely tracked and stored on the blockchain, which would improve the current sustainability related tracking systems that are still commonly base in paper and reports, making them vulnerable to fraud and error (Kshetri, 2018). An example of this is storing certification of sustainability and facilitate an uninterrupted chain of custody by tracking it on blockchain, which would prove its authenticity (Abeyratne & Monfared, 2016; Sarkis, 2017; Steiner & Baker, 2015). Blockchain enabled traceability could be especially useful in a particularly important part of GSCM, reverse logistics, which is characterized with high uncertainty of the location and amount of products and materials at the end of life stage of products, making it hard to evaluate the supply to be taken back (Saberi et al., 2018).

Blockchain could also promote the integration of these information systems between supply chain parties; every member of the system would have access to the information without having to fear that another member has tampered with the information, because no single participant controls information (Iansiti & Lakhani, 2017). Nevertheless, even though the blockchain could provide a solution to the lack of an information and traceability system as described, it requires resources such as IT infrastructure and capabilities that can be a further challenge for GSCM (Abeyratne & Monfared, 2016).

5.4 Effect on transparency

As discussed in the context of blockchain in supply chains, traceability of products and information is not sufficient and requires transparency of information to be reliable. Blockchain has been described by many researchers to increase transparency in supply chains(Abeyratne & Monfared, 2016; Casey & Wong, 2017; Kshetri, 2018; Steiner &

Baker, 2015; Tian, 2016) The decentralized and immutable nature of blockchain allows every party in the supply chain to access, inspect and audit information that is considered reliable in real-time (Casey & Wong, 2017). This combined with the tracking of information of blockchain can solve some of the barriers of complexity and fragmentation of supply chain management but especially GSCM, where visibility into cloudy, upstream parts of the supply chain are necessary to manage environmental sustainability as described above (Srivastava, 2007; Vachon & Klassen, 2006).

5.5 Effect on customer demand and knowledge

Blockchain is a potential solution to the barrier of lack of customer demand and knowledge by providing reliable and real-time time information of the product's journey through the value chain, thus authenticating sustainability claims of a given product (Kshetri, 2018; Steiner & Baker, 2015). This would make it easier for customers to evaluate the sustainability of the products since the information would be available immediately and the customer would not need to evaluate the authenticity of the claims, as opposed to researching for example different certification schemes and evaluating their credibility and claims of sustainability (Casey & Wong, 2017; Young et al., 2010). Therefore, blockchain could increase the demand for sustainable products and services by reducing the time needed to research sustainable products and by providing adequate information of the whole product life cycle, which were the reasons for lack of consumer demand identified by Young (2010). All in all blockchain would allow customers to make more informed consumption decisions and verify claims of sustainability (Tian, 2016). Furthermore, as customers become more interested in the sustainability and origins of their products, providing them tools to verify provenance will be at first a source of competitive advantage but later a necessity if competitors adopt the system.

5.6 Effect on trust

As a result of the benefits of traceability and transparency above, blockchain has the ability to increase trust between the different actors of the supply chain. With blockchain the need for trust, or a third party to facilitate that trust is replaced by cryptography that ensures the security and immutability of the information (Nakamoto, 2008). From the viewpoint of the focal company, they would be able to trust that the information they receive from suppliers is reliable and tamperproof and vice versa, which would promote information sharing and collaboration in supply chains (Agi & Nishant, 2017; Cheng et al., 2008). The use of smart contract would further increase trust between supply chain members because the execution and enforcement of contracts would be automated, making interactions predictable (Christidis & Devetsikiotis, 2016).

In the case of the customer, they could trust the environmental sustainability of the company because of the visibility to the entire supply chain (Steiner & Baker, 2015; Tian, 2016). Because of the fact that the information of the journey of a product can be verified greenwashing would most likely decrease since it would be easy to call out. Anyone is able to see from the information on the blockchain which companies are actually sustainable and not only using sustainability for marketing purposes. Furthermore, it could be argued that the decrease of greenwashing would have an overall positive effect on the investor and consumer confidence and trust in the market of green products.

Green supply chain management challenge	**Potential of blockchain technology**
Cost concerns	Increases the cost of initial investment in GSCM
	Decreases transaction costs by removing of third parties and increasing trust
	Decreases costs by automating contracting processes with smart contracts
Issues in assessing environmental performance	Improves the measurement of environmental performance by making sustainability indicators more quantifiable
	Provides more reliable information, which improves evaluation of environmental performance
Lack of integrated information and traceability systems	Combined with IoT enables the secure tracking of products through each step of the supply chain
	Decentralization and immutability promote integration of information systems with other supply chain partners
Lack of transparency	Decentralization and immutability of information increases transparency of the supply chain
Lack of customer demand and knowledge	Blockchain provided real-time visibility into the supply chain enables consumers to make better consumption decision based on real-time and reliable information
Lack of trust	Information on blockchain is reliable, secure and tamperproof, which promotes trust between members of the supply chain
	Use of smart contracts increases trust by executing and enforcing pre-determined agreements
	Blockchain provided transparency could increase the trust of customers in sustainable products by making greenwashing easier to call out

Table 1: The potential of blockchain in solving GSCM challenges

6 DISCUSSIONS

Blockchain is an emerging, hyped technology that has been said to disrupt and revolutionize industries and parts of society. One of the many applications of the technology is in the context of supply chain management and environmental sustainability. Increasing stakeholder pressure, regulation and the environmental as well as economic performance improvements associated with GSCM has fuelled its interest in research and practice. The goal of this thesis was to combine these rising subjects and explore how blockchain technology can impact the challenges of GSCM. This was done by studying literature of the characteristics of blockchain technology and GSCM respectively. Based on the observations a general framework of the potential solutions of blockchain technology to GSCM challenges was developed. Blockchain can potentially solve or be part of the solution to challenges in GSCM such as cost concerns, issues in measuring environmental performance, lack of traceability, lack of customer demand and knowledge, lack of transparency and lack of trust. Many of these relate to the core characteristics of the technology such as decentralization and immutability and reliability of the information as well as the concept of smart contracts. Nevertheless, it should be underlined that blockchain is by no means a quick solution to a given GSCM challenge, but a potential part of the solution based on the benefits of its characteristics.

Despite the benefits, blockchain technology is at a rather early stage and faces plenty of challenges before it can be widely adopted in the supply chain, including technological, organizational, cultural and behavioural challenges such as cost of deployment, scalability, immaturity, lack of standards, top management support, organizational policies, governmental support and the expertise of employees.

Many of the possible solutions that blockchain could provide to GSCM are relevant also in traditional supply chain management such as increasing trust and visibility to the supply chain. Nevertheless, it could be argued they are especially important in GSCM because of need to control the full value chain of the product from raw material extraction to end-of-use in order to manage environmental sustainability in supply chains. Also, because supply chains are such a crucial part of managing global environmental impacts, GSCM should not be a subcategory of supply chain management but a core part of its definition.

6.1 Implications to research and practice

This thesis adds to the novel but fast-growing research topic of blockchain and its applications. The research on blockchain in the supply chain context is still sparse and practically non-existent in the context of GSCM. Therefore, this thesis provides a new contribution to the knowledge of the potential use of the emergent technology in this particular subject area. Regarding the practical implications, this thesis provides supply chain and environmental management professionals more understanding of the much-hyped technology and its benefits for green supply chains.

6.2 Limitations and future research

This thesis is an exploratory contribution to the early stage field of blockchain technology in GSCM and further research on the subject is required extensively such as its implementation, performance, challenges and limitations to know when and if blockchain technology is appropriate in a given industry, area, and activity in the green supply chain. Specifically, this thesis lacks the comparison of blockchain technology to existing information system solutions to the identified challenges, which should be addressed in future research. Another limitation of this thesis is limiting it to cover only the environmental dimension of sustainability in the context of supply chain management, and therefore future research on the interaction of all three dimensions of sustainability (environmental, social and economic) is suggested, since it has been identified to be lacking. Also, there is plenty of room for studies on blockchain's role in various GSCM practices mentioned above. One of the suggestion for research is conducting industry specific studies on how blockchain can impact the sustainability in supply chains, since industries vary in performance and in their needs for sustainability (Rajeev et al., 2017).

Bibliography

Abeyratne, S. A., & Monfared, R. . (2016). Blockchain ready manufacturing supply chain using distributed ledger. *International Journal of Research in Engineering and Technology*, *5*(9), 1–10.

Agi, M. A. N., & Nishant, R. (2017). Understanding influential factors on implementing green supply chain management practices: An interpretive structural modelling analysis. *Journal of Environmental Management*, *188*, 351–363.

Agyemang, M., Zhu, Q., Adzanyo, M., Antarciuc, E., & Zhao, S. (2018). Evaluating barriers to green supply chain redesign and implementation of related practices in the West Africa cashew industry. *Resources, Conservation and Recycling*, *136*, 209–222.

Agyemang, M., Zhu, Q., & Tian, Y. (2016). Analysis of opportunities for greenhouse emission reduction in the global supply chains of cashew industry in West Africa. *Journal of Cleaner Production*, *115*, 149–161.

Ahi, P., & Searcy, C. (2013). A comparative literature analysis of definitions for green and sustainable supply chain management. *Journal of Cleaner Production*, *52*, 329–341.

Azevedo, S. G., Carvalho, H., & Cruz Machado, V. (2011). The influence of green practices on supply chain performance: A case study approach. *Transportation Research Part E: Logistics and Transportation Review*, *47*(6), 850–871.

Buck, J. (2018). Ibm and maersk start promised blockchain supply chain company. Retrieved March 18, 2018, from https://cointelegraph.com/news/ibm-and-maersk-start-promised-blockchain-supply-chain-company

Casey, M. J., & Wong, P. (2017, March 13). Global Supply Chains Are About to Get Better, Thanks to Blockchain. *Harvard Business Review*. Retrieved from https://hbr.org/2017/03/global-supply-chains-are-about-to-get-better-thanks-to-blockchain

Catalini, C. (2017, March 2). How blockchain applications will move beyond finance. *Harvard Business Review*. Retrieved March, 15th, 2018, from https://hbr.org/2017/03/how-blockchain-applications-will-move-beyond-finance

Chapron, G. (2017). The environment needs cryptogovernance. *Nature*, *545*(7655), 403–405.

Cheng, J., Yeh, C., & Tu, C. (2008). Trust and knowledge sharing in green supply chains. *Supply Chain Management: An International Journal*, *13*(4), 283–295.

Christidis, K., & Devetsikiotis, M. (2016). Blockchains and Smart Contracts for the Internet of Things. *IEEE Access*, *4*, 2292–2303.

Christopher, M., & Towill, D. (2001). An integrated model for the design of agile supply chains. *International Journal of Physical Distribution & Logistics Management*, *31*(4), 235–246.

de Oliveira, U. R., Espindola, L. S., da Silva, I. R., da Silva, I. N., & Rocha, H. M. (2018). A systematic literature review on green supply chain management: Research implications and future perspectives. *Journal of Cleaner Production*, *187*, 537–561.

Dekker, R., Bloemhof, J., & Mallidis, I. (2012). Operations research for green logistics – An overview of aspects, issues, contributions and challenges. *European Journal of Operational Research*, *219*(3), 671–679.

Delgado, M., & Mills, K. (2018). The supply chain economy and the future of good jobs in america. *Harvard Business Review* Retrieved March 21, 2018, from https://hbr.org/2018/03/the-supply-chain-economy-and-the-future-of-good-jobs-in-america

Delmas, M. A., & Burbano, V. C. (2011). The drivers of greenwashing. *California Management Review*, *54*(1), 64–87.

Ehrgott, M., Reimann, F., Kaufmann, L., & Carter, C. R. (2013). Environmental development of emerging economy suppliers: antecedents and outcomes. *Journal of Business Logistics*, *34*(2), 131–147.

Elkington, J. (1998). Partnerships fromcannibals with forks: The triple bottom line of 21st-century business. *Environmental Quality Management*, *8*(1), 37–51.

Foerstl, K., Meinlschmidt, J., & Busse, C. (2018). It's a match! Choosing information processing mechanisms to address sustainability-related uncertainty in sustainable supply management. *Journal of Purchasing and Supply Management*, *24*(3), 204–217.

Foerstl, K., Schleper, M. C., & Henke, M. (2017). Purchasing and supply management: From efficiency to effectiveness in an integrated supply chain. *Journal of Purchasing and Supply Management*, *23*(4), 223–228.

Fung, A. (2013). Infotopia: Unleashing the democratic power of transparency. *Politics & Society*, *41*(2), 183–212.

Global Footprint Network. (2018). www.footprintnetwork.org. Retrieved August 6, 2018, from https://www.footprintnetwork.org/

Govindan, K., Kaliyan, M., Kannan, D., & Haq, A. N. (2014). Barriers analysis for green supply chain management implementation in Indian industries using analytic hierarchy process. *International Journal of Production Economics*, *147*, 555–568.

Govindan, K., Khodaverdi, R., & Vafadarnikjoo, A. (2015). Intuitionistic fuzzy based DEMATEL method for developing green practices and performances in a green supply chain. *Expert Systems with Applications*, *42*(20), 7207–7220.

Green, K. W., Zelbst, P. J., Bhadauria, V. S., & Meacham, J. (2012). Do environmental collaboration and monitoring enhance organizational performance? *Industrial Management & Data Systems*, *112*(2), 186–205.

Gupta, V. (2017a.). A brief history of blockchain. *Harvard Business Review*. Retrieved March 14, 2018, from http://web.b.ebscohost.com.libproxy.aalto.fi/ehost/pdfviewer/pdfviewer?vid=2&sid=944e7e2b-27f7-4724-9ff6-0c3c26d5fd79%40pdc-v-sessmgr01

Gupta, V. (2017b). The promise of blockchain is a world without middlemen. *Harvard Business Review*. Retrieved March 31, 2018, from https://hbr.org/2017/03/the-promise-of-blockchain-is-a-world-without-middlemen.

Hervani, A. A., Helms, M. M., & Sarkis, J. (2005). Performance measurement for green supply chain management. *Benchmarking: An International Journal*, *12*(4), 330–353.

Hoejmose, S., Brammer, S., & Millington, A. (2012). "Green" supply chain management: The role of trust and top management in B2B and B2C markets. *Industrial Marketing Management*, *41*(4), 609–620.

Iansiti, M., & Lakhani, K. R. (2017). The Truth About Blockchain. *Harvard Business Review*. Retrieved March 13, 2018, from https://hbr.org/2017/01/the-truth-about-blockchain.

International Data Group. (2018). New idc spending guide sees worldwide blockchain spending growing to $9.7 billion in 2021. Retrieved March 13, 2018, from https://www.idc.com/getdoc.jsp?containerId=prUS43526618

Kelepouris, T., Pramatari, K., & Doukidis, G. (2007). RFID-enabled traceability in the food supply chain. *Industrial Management & Data Systems*, *107*(2), 183–200.

Khaqqi, K. N., Sikorski, J. J., Hadinoto, K., & Kraft, M. (2018). Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application. *Applied Energy*, *209*, 8–19.

Kosba, A., Miller, A., Shi, E., Wen, Z., & Papamanthou, C. (2016). Hawk: the blockchain model of cryptography and privacy-preserving smart contracts. In *2016 IEEE Symposium on Security and Privacy (SP)* (pp. 839–858). IEEE.

Kshetri, N. (2018). 1 Blockchain's roles in meeting key supply chain management objectives. *International Journal of Information Management*, *39*, 80–89.

Lambert, D. M., Cooper, M. C., & Pagh, J. D. (1998). The international journal of logistics management supply chain management: implementation issues and research opportunities. *The International Journal of Logistics Management*, *9*(2), 1–20.

Linton, J., Klassen, R., & Jayaraman, V. (2007). Sustainable Supply Chains: An Introduction. *Journal of Operations Management*, *25*(6), 1075–1082.

Lodico, M. G., Spaulding, D. T., & Voegtle, K. H. (2010). Methods in educational research from theory to practice. San Francisco: John Wiley & Sons.

Luthra, S., Kumar, V., Kumar, S., & Haleem, A. (2011). Barriers to implement green supply chain management in automobile industry using interpretive structural modeling technique: An Indian perspective. *Journal of Industrial Engineering and Management*, *4*(2).

Min, H., & Galle, W. P. (2001). Green purchasing practices of US firms. *International Journal of Operations & Production Management*, *21*(9), 1222–1238.

Nakamoto, S. (2008). Bitcoin: a peer-to-peer electronic cash system. Retrieved February 22, 2018, from www.bitcoin.org.

Nakasumi, M. (2017). Information Sharing for Supply Chain Management Based on Block Chain Technology. In *2017 IEEE 19th Conference on Business Informatics (CBI)* (pp. 140–149). IEEE.

New, S. (2010). The Transparent Supply Chain. *Harvard Business Review, Issue 10*. Retrieved August 10th, 2018 from https://www-scopus-com.libproxy.aalto.fi/record/display.uri?eid=2-s2.0-77958510368&origin=resultslist&sort=plf-f&src=s&st1=%22the+transparent+supply+chain%22&st2=&sid=efb671fba7df9d59b45855e8e47b232f&sot=b&sdt=b&sl=37&s=TITLE%28%22the+transparent+supply+c

Rajeev, A., Pati, R. K., Padhi, S. S., & Govindan, K. (2017). Evolution of sustainability in supply chain management: A literature review. *Journal of Cleaner Production*, *162*, 299–314.

Rao, P., & Holt, D. (2005). Do green supply chains lead to competitiveness and economic performance? *International Journal of Operations & Production Management*, *25*(9), 898–916.

Rauer, J., & Kaufmann, L. (2015). Mitigating External Barriers to Implementing Green Supply Chain Management: A Grounded Theory Investigation of Green-Tech Companies' Rare Earth Metals Supply Chains. *Journal of Supply Chain Management*, *51*(2), 65–88.

Saberi, S., Kouhizadeh, M., & Sarkis, J. (2018). Blockchain technology: A panacea or pariah for resources conservation and recycling? *Resources, Conservation and Recycling*, *130*, 80–81.

Sarkis, J. (2012). A boundaries and flows perspective of green supply chain management. *Supply Chain Management: An International Journal*, *17*(2), 202–216.

Sarkis, J. (2017). *Green supply chain management - a concise introduction*. Routledge.

Seuring, S., & Gold, S. (2012). Conducting content-analysis based literature reviews in supply chain management. *Supply Chain Management: An International Journal*, *17*(5), 544–555.

Seuring, S., & Müller, M. (2008a). Core issues in sustainable supply chain management - a Delphi study. *Business Strategy and the Environment*, *17*(8), 455–466.

Seuring, S., & Müller, M. (2008b). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, *16*(15), 1699–1710.

Shan, W., & Wang, J. (2018). Mapping the landscape and evolutions of green supply chain management. *Sustainability*, *10*(3), 597.

Srivastava, S. K. (2007). Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews*, *9*(1), 53–80.

Steiner, J., & Baker, J. (2015). Blockchain: the solution for transparency in product supply chains. Retrieved March 8th, 2018 from https://www.provenance.org/whitepaper

Swan, M. (2015). *Blockchain: Blueprint for a New Economy*. O'Reilly Media, Inc.

Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. In *2016 13th International Conference on Service Systems and Service Management (ICSSSM)* (pp. 1–6). IEEE.

Underwood, S. (2016). Blockchain Beyond Bitcoin. *Communications of the ACM*, *59*(11).

UNDP. (2018). *The future is decentralized - Block chains, distributed ledgers and the future of sustainable development*. Retrieved August 15th, 2018 from http://www.undp.org/content/undp/en/home/librarypage/corporate/the-future-is-decentralised.html

Vachon, S., & Klassen, R. D. (2006). Extending green practices across the supply chain. *International Journal of Operations & Production Management*, *26*(7), 795–821.

Vanalle, R. M., Ganga, G. M. D., Godinho Filho, M., & Lucato, W. C. (2017). Green supply chain management: An investigation of pressures, practices, and performance within the Brazilian automotive supply chain. *Journal of Cleaner Production*, *151*, 250–259.

Vranken, H. (2017). Sustainability of bitcoin and blockchains. *Current Opinion in Environmental Sustainability*, *28*, 1–9.

Walker, H., Di Sisto, L., & McBain, D. (2008). Drivers and barriers to environmental supply chain management practices: Lessons from the public and private sectors. *Journal of Purchasing and Supply Management*, *14*(1), 69–85.

WCED. (1987). *Our Common Future*.

World Economic Forum. (2015). *Deep Shift: Tehcnology Tipping Points and Societal Impact*. Retrieved March 10th, 2018 from http://www3.weforum.org/docs/WEF_GAC15_Technological_Tipping_Points_report_2015.pdf

Yli-Huumo, J., Ko, D., Choi, S., Park, S., & Smolander, K. (2016). Where Is Current Research on Blockchain Technology?—A Systematic Review. *PLOS ONE*, *11*(10).

Young, W., Hwang, K., McDonald, S., & Oates, C. J. (2010). Sustainable consumption: green consumer behaviour when purchasing products. *Sustainable Development, 18 (1), 20-31*.

Zhu, Q., & Sarkis, J. (2004). Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. *Journal of Operations Management*, *22*(3), 265–289.

Zhu, Q., Sarkis, J., & Geng, Y. (2005). Green supply chain management in China: pressures, practices and performance. *International Journal of Operations & Production Management*, *25*(5), 449–468.

Zhu, Q., Sarkis, J., & Lai, K. (2008). Confirmation of a measurement model for green supply chain management practices implementation. *International Journal of Production Economics*, *111*(2), 261–273.

Zhu, Q., Sarkis, J., & Lai, K. (2013). Institutional-based antecedents and performance outcomes of internal and external green supply chain management practices. *Journal of Purchasing and Supply Management*, *19*(2), 106–117.

Ølnes, S., Ubacht, J., & Janssen, M. (2017). Blockchain in government: Benefits and implications of distributed ledger technology for information sharing. *Government Information Quarterly*, *34*(3), 355–364.